THIRD EDITION

NYSORA
CONTINUING MEDICAL EDUCATION

HADZIC'S PERIPHERAL NERVE BLOCKS

AND ANATOMY FOR ULTRASOUND-GUIDED REGIONAL ANESTHESIA

ADMIR HADZIC

EDITION EDITORS: ANA M. LOPEZ
ANGELA LUCIA BALOCCO • CATHERINE VANDEPITTE

Mc Graw Hill

NEW YORK SCHOOL OF REGIONAL ANESTHESIA

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DEDICATION

We dedicate this book to Jerry Vloka, MD, PhD
in recognition of his pioneering contributions to regional anesthesia
and immense inspiration for generations of students
and scholars of anesthesiology.

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FOREWORD

The third edition of this standard textbook on ultrasound nerve blocks is released during a unique period in human history. The COVID-19 pandemic and the threats that the disease poses to both patients and healthcare workers have substantially changed perioperative practice. During the pandemic, regional anesthesia was established as the preferred method over general anesthesia whenever possible. Nerve blocks preserve respiratory function and avoid aerosolization during intubation and extubation and, hence, viral transmission to other patients and healthcare workers. As an example, the use of nerve blocks as the preferred surgical anesthesia method during the pandemic allowed many limb surgeries to be carried out with decreased exposure to healthcare workers and less burden on post-anesthesia care units (PACUs) and utilization of hospital beds. With regional anesthesia, patients can leave acute postoperative care facilities faster and avoid admission to the limited hospitalization beds. In our center, using regional anesthesia and nerve blocks as the main anesthetic choice allowed elective orthopedic surgery in many patients.

The use of ultrasound-guided local regional anesthesia (LRA) has increased exponentially in the last few years. The traditional techniques have been refined and a number of new approaches have been devised to better suit the evolving clinical practice. Nerve blocks are an essential component of multimodal analgesia in enhanced recovery after surgery (ERAS) protocols. Their use enhances analgesia and reduces or eliminates the use of opioids in the postoperative period. Some traditional nerve block techniques have been substituted by more selective techniques to minimize motor block and facilitate early rehabilitation and recovery. New ultrasound-guided fascial plane techniques, distal nerve blocks, and selective periarticular injections also are increasingly being used to yield a better balance between efficacy, simplicity, safety, and sensory-motor block ratio.

This third edition of NYSORA's textbook is substantially updated and revised to include the many new developments in regional anesthesia and trends in clinical practice. The new edition features entirely new artwork, new clinical images, and new fascial plane and infiltration techniques. All in all, some 500 new algorithms, illustrations, ultrasound images, clinical photographs, and cognitive aids were included to facilitate learning. In addition to anesthesiologists, the highly didactic and organized technique descriptions and functional anatomy principles will be valuable to all anesthesia providers, acute and chronic pain specialists, as well as interventional pain, musculoskeletal medicine, and emergency department physicians.

NYSORA's Reverse Ultrasound Anatomy™ (RUA) images feature functional anatomy or block techniques with clear instructions on the principles and goals of each given technique. These cognitive aids entailed countless hours of work and collaboration between NYSORA's creative and editorial teams to develop highly didactic creatives that facilitate understanding of the anatomy, fascial planes, and principles of nerve blockade. RUA helps students memorize sonoanatomy patterns, which is essential for ultrasound imaging. The knowledge of the sonoanatomy patterns substantially increases ultrasound proficiency and skills retention. Wherever applicable, clinical images of the patient's position, ultrasound transducer placement, and anatomical detail are featured. Recent relevant literature was added to the "Suggested Reading" for readers who like to explore the original sources of the information presented. We chose this approach in an effort to provide the most practical, pragmatic information and relieve the content from massive literature citations.

Readers should be advised that this book is not meant to be an encyclopedic listing of all techniques and their variations. Rather, our textbook should be viewed as a compendium of well-established knowledge, didactically organized for learning, and transferring knowledge to students of anesthesiology. With this approach, the textbook aims to help standardize, and implement well-established techniques, indications, pharmacology, monitoring, and the documentation of nerve blocks. Instead of burdening the reader with experimental block techniques with unproven clinical benefit, we aimed to include the most clinically useful nerve block, fascial, and infiltration techniques with proven efficacy and clinical applicability. Information about perioperative management and local anesthetic toxicity treatment was also added, and/or fully revised. Because patients commonly present with a vague history of allergy to local anesthetics, the new edition also features highly practical algorithms to facilitate decision-making and management of allergy to local anesthetics.

We are confident that this textbook will continue to be one of the primary resources on peripheral nerve blocks in medical practices worldwide.

Sincerely,

Drs Hadzic, Lopez, Balocco, and Vandepitte

Free access to online videos at www.accessanesthesiology.com. Search for this title in the library and select "View All Videos" in the Multimedia widget on the landing page of the book.

ACKNOWLEDGMENTS

This book would not be possible without the extraordinary people who contributed their time and talent and undying commitment to create an educational masterpiece. Many thanks to Drs Ana Lopez (senior editor), Angela Lucia Balocco, and Catherine Vandepitte, the third edition editors. Their combination of commitment, knowledge, research, and clinical expertise is apparent on every page of this book.

Many thanks to the leadership at Ziekenhuis Oost-Limburg (ZOL; Genk, Belgium) for their support and for facilitating a creative platform in the hospital's clinical setting. In particular, many thanks to the medical director, Dr. Griet Vander Velpen, and the "can-solve-all" manager, Chantal Desticker. Without your support, this book, and the creation of our center of excellence for regional anesthesia at ZOL, would not be possible. Thank you to the leadership of the department, especially Rene Heylen, Jan Van Zundert, and Pieter De Vooght; their vision led to the creation of one of the best regional anesthesia centers in the heart of Europe. Thank you to our regional anesthesia team and block nurses Birgit Lohmar, Joelle Caretta, Ine Vanweert, Kristell Broux, Ilse Cardinaels, Sydney Herfs, Elke Janssen, Hüda Erdem, Mohamed Rafiq, Danny Baens, and all the operating nurses in the N-Block at the orthopedic surgery unit.

Many thanks to all top fellows in regional anesthesia. These young, bright doctors contribute immense value to our teaching mission, and carry on the mission of national ambassadors of regional anesthesia after graduation. Big gratitude to our anesthesia residents who rotate through our service from their mothership Universities: Leuven (KUL), Gent, Antwerp, and others.

Our orthopedic surgery department is by all means one of the best in Europe and beyond. Made up of ultra high-achievers; physicians of national, Olympic, and professional football teams; innovators; and above all incredibly skilled and passionate surgeons. It has been an absolute pleasure building the orthopedic anesthesia service with you. A short glimpse at the website of the department of orthopedic surgery at ZOL is sufficient to get a sense that NYSORA-EUROPE at ZOL is flanked by true giants of orthopedic surgery (https://www.zol.be/raadplegingen/orthopedie).

Thank you to the NYSORA International Team: Pat Pokorny (UK), Kusum Dubey (New Delhi), Katherine Hughey-Kubena (USA), Elvira Karovic, Medina Brajkovic, Ismar Ruznjic (B&H), Nenad Markovic (SER), Jill Vanhaeren, and Greet van Meir (BE). This is an incredible team of NYSORA's go-getters.

Thank you to NYSORA's illustrator Ismar Ruznjic for the new-style illustrations and artwork he imparted to this edition. Ismar has grown with NYSORA to become one of the world's very best anatomy illustrators.

A big thank you to our designer and 3-D maestro, Nenad Markovic, an ultimate perfectionist, whose eye has been constructively critical to many artistic and stylistic aspects of this book, and NYSORA's content at large.

Finally, a huge thanks to all the contributors to this book, as there have been quite a few. Such a volume, packed with so much anatomical information, can always have hidden errors. We have relied on our stellar contributors to detect and correct them wherever possible. However, should the readers find any that we have missed that require correction, please forward them to info@nysora.com. We vouch to improve upon them and thank you immensely in advance for your feedback.

Many thanks to all,

Editors

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SECTION 1

Foundations

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1 Functional Regional Anesthesia Anatomy

Knowledge of anatomy is essential for the practice of regional anesthesia and ultrasound-guided regional anesthesia procedures. This chapter provides a concise overview of the essential functional anatomy necessary for the implementation of traditional and ultrasound-guided regional anesthesia techniques. Figure 1-1 demonstrates the anatomical planes and directions used as a conventional approach throughout the book.

Anatomy of Peripheral Nerves

The neuron is the basic functional unit responsible for nerve conduction. Neurons are the longest cells in the body, often as long as 1 meter. Most neurons have a limited ability to repair after injury. Advances in the understanding of the neurobiology of nerve regeneration and experimental advances in biotechnology may eventually result in development of the strategies to promote axonal growth and reduce neuronal death.

A typical neuron consists of a cell body (soma) with a large nucleus. The cell body is attached to several branching processes, called dendrites, and a single axon (Figure 1-2). Dendrites receive incoming messages, whereas single axons per neuron conduct outgoing messages. In peripheral nerves, axons are long and slender; they are often referred to as nerve fibers.

Connective Tissue

The peripheral nerve is composed of three types of fibers: (1) somatosensory or afferent nerves, (2) motor or efferent nerves, and (3) autonomic nerves. In a peripheral

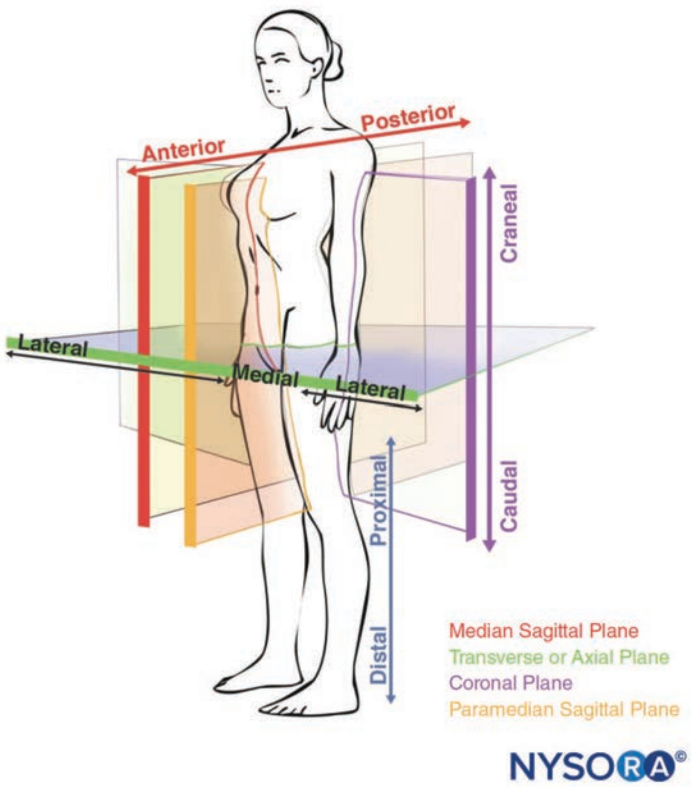

FIGURE 1-1. Conventional body planes and directions. Red, sagittal; orange, sagittal paramedian; green, transverse; and purple, coronal or axial.

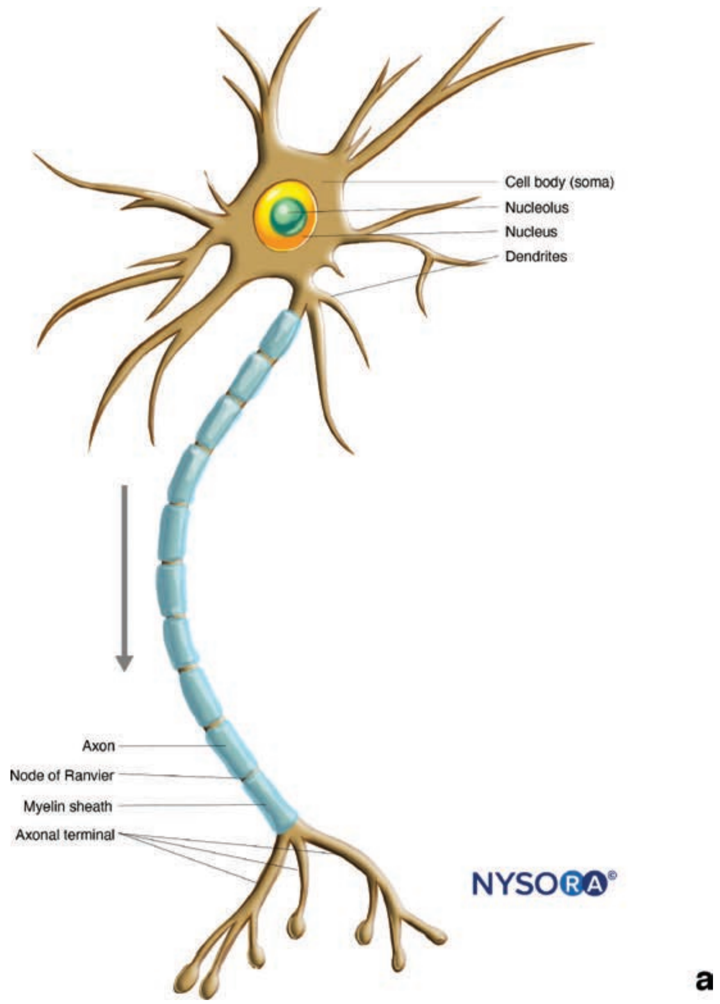

FIGURE 1-2. Composition of the neuron.

nerve (Figure 1-3), individual axons are enveloped in a loose and delicate connective tissue, the **endoneurium.** Groups of axons are arranged within a bundle (nerve fascicle) surrounded by the **perineurium.** The perineurium imparts mechanical strength to the peripheral nerve and functions as a diffusion barrier to the fascicle, isolating the endoneurial space and preserving the ionic milieu of the axon. At each branching point, the perineurium splits with the fascicle. The fascicles, in turn, are embedded in loose connective tissue called the **interfascicular epineurium**, which contains adipose tissue, fibroblasts, mastocytes, blood vessels, and lymphatics. The outer layer surrounding the nerve is the **epineurium,** a denser collagenous tissue that protects the nerve. The **paraneurium** consists of loose connective tissue that holds a stable relationship between adjacent structures filling the space in between them, such as the neurovascular bundles of intermuscular septae. This tissue contributes to the functional mobility of nerves during joint and muscular movement.

Of note, the fascicular bundles are not continuous throughout the peripheral nerve but divide and anastomose with one another as frequently as every few millimeters (Figure 1-4). This arrangement of peripheral nerves helps to explain why intraneural injections, which disrupt this organization, may result in disastrous consequences as opposed to clean needle nerve cuts, which heal more readily. In the vicinity of joints, the fascicles are thinner, more numerous, and are likely surrounded by a greater amount of connective tissue, which reduces the vulnerability of the fascicles to pressure and stretching caused by movement.

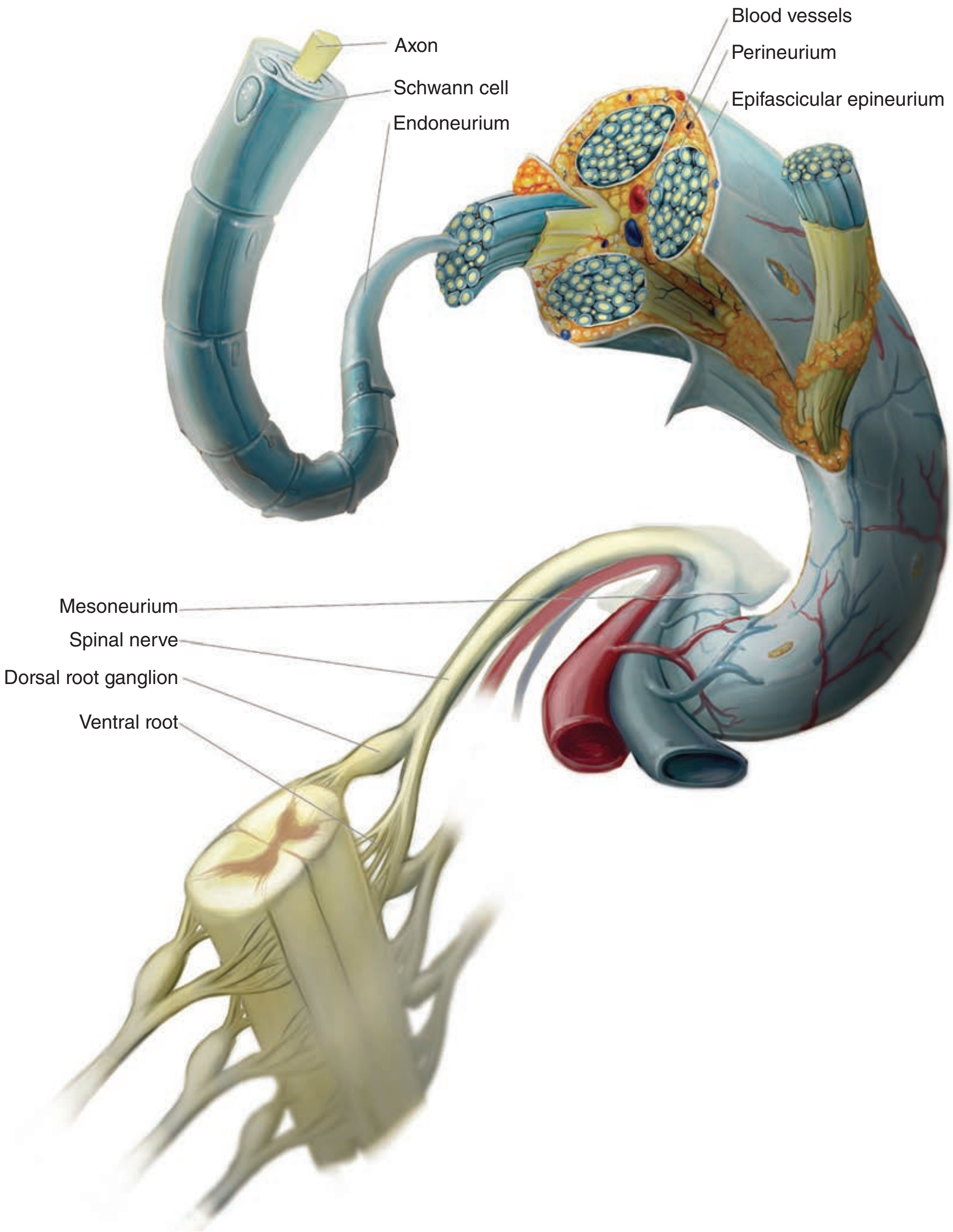

FIGURE 1-3. Organization of the peripheral nerve.

Peripheral nerves receive blood supply from the adjacent blood vessels running along their course. There are two independent interconnected vascular systems. The extrinsic system consists of arteries, arterioles, and veins that lie within the epineurium. The intrinsic vascular system comprises a group of longitudinal capillaries that run within the fascicles and endoneurium. Neuronal injury after nerve blockade may be due, at least partly, to the pressure or stretch within connective sheaths and the consequent interference with the vascular supply to the nerve.

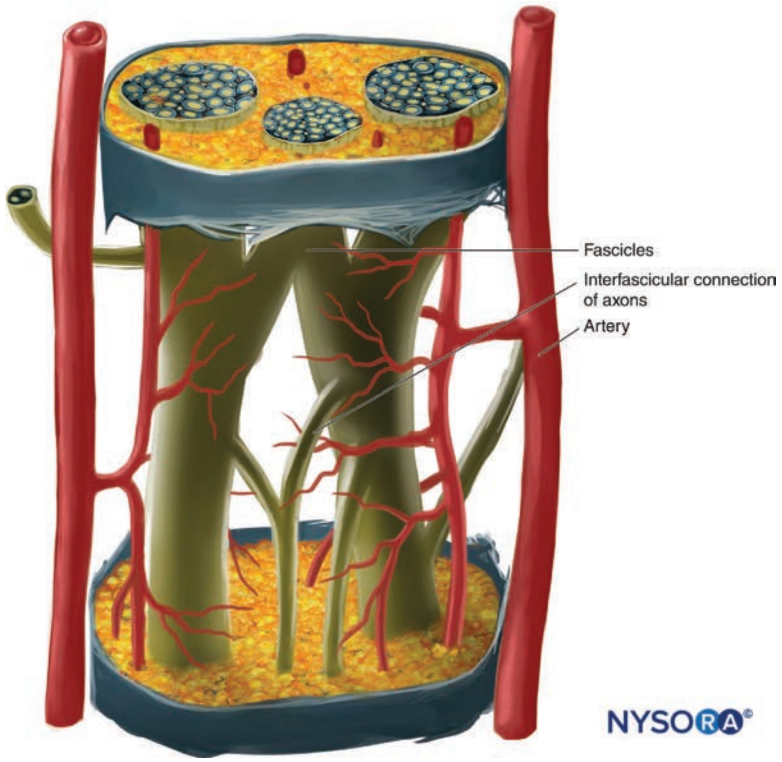

FIGURE 1-4. Diagram of fascicular arrangement in a peripheral nerve.

Communication Between the Central Nervous System and Peripheral Nervous Systems

The central nervous system (CNS) communicates with the body through spinal nerves, which have sensory and motor components (Figure 1-5). The sensory fibers arise from neurons in the dorsal root ganglia and enter the dorsolateral aspect of the spinal cord to form the dorsal root. The motor fibers arise from neurons in the ventral horn of the spinal cord and pass through the ventrolateral aspect of the spinal cord to form the ventral root. The dorsal and ventral *roots* converge in the intervertebral foramen to form the spinal nerves, which then divide into dorsal and ventral *rami*. The dorsal rami innervate muscles,

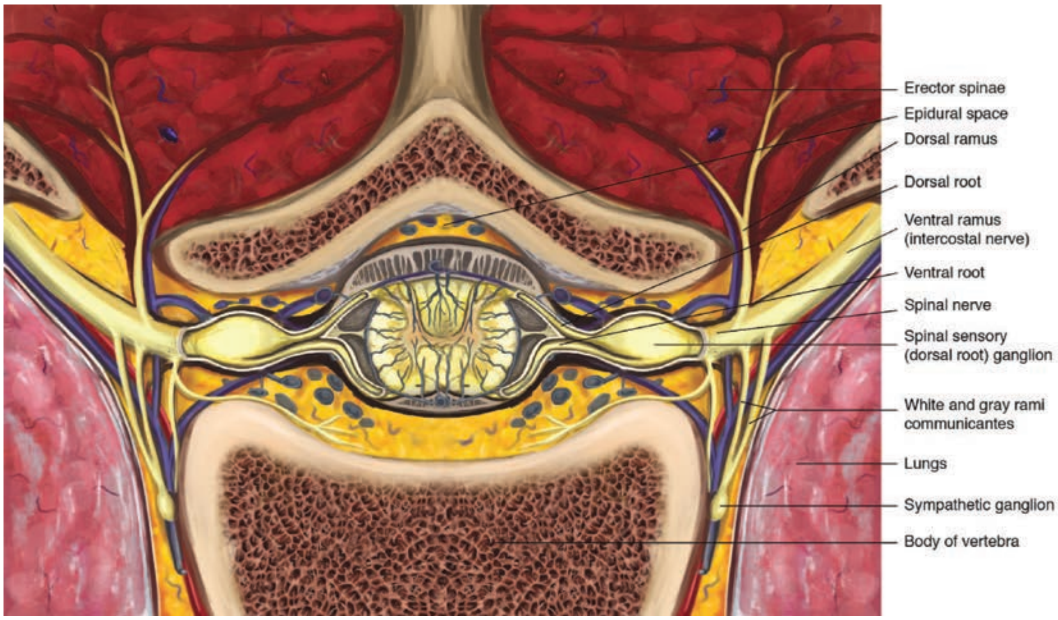

FIGURE 1-5. Schematic transverse section of thoracic vertebra showing the spine and the origin of spinal nerves.

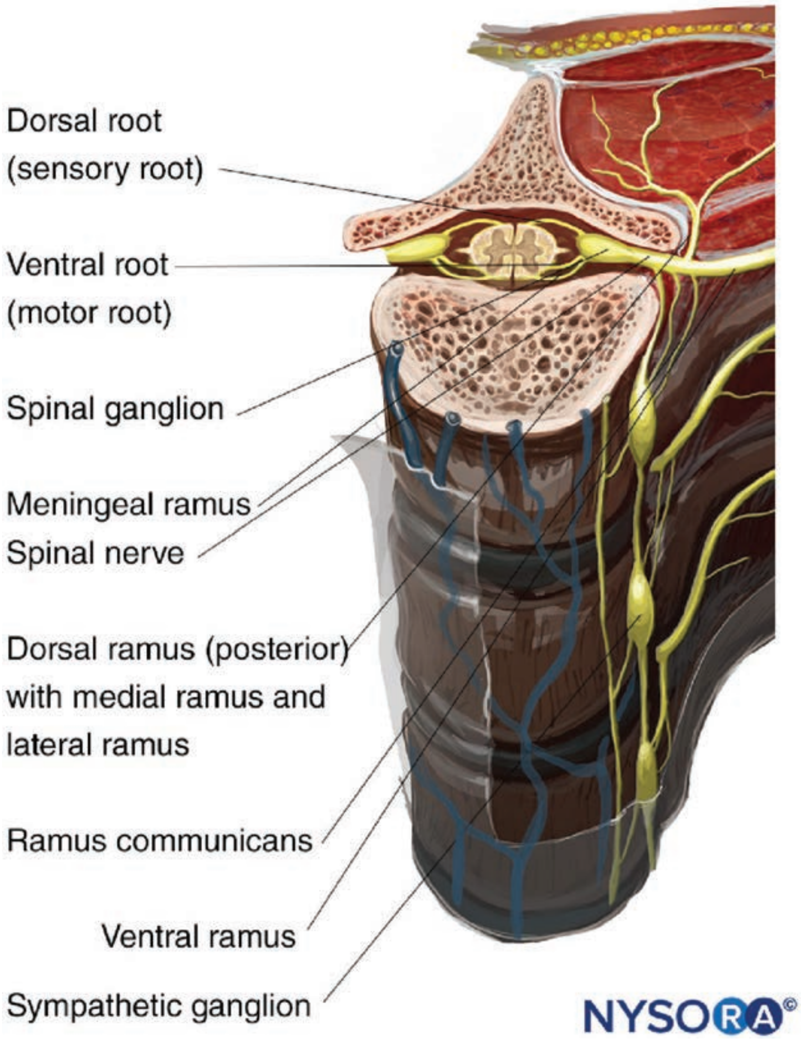

FIGURE 1-6. Anatomy of a typical spinal intercostal nerve.

bones, joints, and the skin of the back along the posterior midline. The ventral rami innervate muscles, bones, joints, and the skin of the antero-lateral aspect of the neck, thorax, abdomen, pelvis, and the extremities (Figure 1-6).

Spinal Nerves

There are 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal. Spinal nerves pass through the vertebral column at the intervertebral foramina (Figure 1-7). The first cervical nerve (C1) passes superior to the C1 vertebra (atlas). The second cervical nerve (C2) passes between the C1 (atlas) and C2 (axis) vertebrae. This pattern continues down the cervical spine; however, because there is no C8 vertebra, the C8 nerve passes between the C7 and T1 vertebrae.

In the thoracic region, the T1 nerve passes between the T1 and T2 vertebrae. This pattern continues down through the remainder of the spine. The vertebral arch of the fifth sacral and first coccygeal vertebrae is rudimentary. Because of this, the vertebral canal opens inferiorly at the sacral hiatus, where the fifth sacral and first coccygeal nerves pass. Roots of spinal nerves must descend through the vertebral canal before exiting the vertebral column through the appropriate intervertebral foramen since the inferior end of the spinal cord (conus medullaris) is located at the L1-L2 vertebral level in adults. Collectively, these roots are called the cauda equina.

Outside the vertebral column, ventral rami from cervical and lumbosacral spinal levels coalesce to form intricate

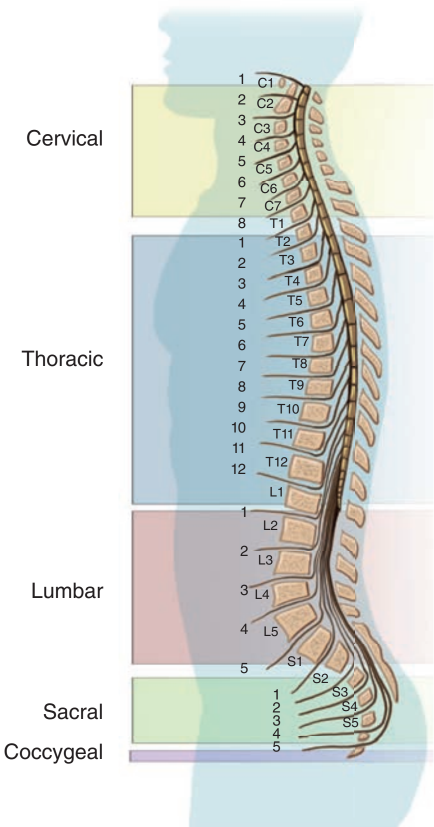

FIGURE 1-7. Spinal nerves.

networks called plexuses from which nerves extend into the neck, the arms, and the legs.

Dermatomes, Myotomes, and Osteotomes

A **dermatome** is the area of the skin supplied by the dorsal (sensory) root of a specific spinal nerve (Figure 1-8). In the trunk, each segment is horizontally disposed, except C1, which does not have a sensory component. The dermatomes of the limbs from the fifth cervical to the first thoracic nerve (C5-T1) and from the third lumbar to the second sacral vertebrae (L3-S2) extend like a series of bands from the midline of the trunk posteriorly into the limbs. Of note, there is considerable overlapping between adjacent dermatomes.

A **myotome** is the segmental innervation of skeletal muscle by a ventral root of a specific spinal nerve (Figure 1-8). An **osteotome** is the area of the bone supplied by the sensory root of the specific spinal nerve.

Distribution of dermatomes, myotomes, and osteotomes does not follow the same pattern in some areas, where different nerves supply the innervation of deep and superficial structures (Figure 1-8). Regardless, the knowledge of their distribution is relevant for the application of regional anesthesia as a guide to decide which block techniques are appropriate to provide adequate analgesia and anesthesia for specific surgical procedures.

Thoracic and Abdominal Wall

Thoracic Wall

The intercostal nerves originate from the ventral rami of the first 11 thoracic spinal nerves (T1-T11). Each intercostal nerve becomes part of the neurovascular bundle of the rib and provides sensory and motor innervations (Figure 1-9).

Except for the first, each intercostal nerve gives off a lateral cutaneous branch that pierces the overlying muscle near the midaxillary line. This cutaneous nerve divides into anterior and posterior branches, which supply the adjacent skin. The intercostal nerves from the second to the sixth space reach the anterior thoracic wall and pierce the superficial fascia near the lateral border of the sternum and divide into medial and lateral cutaneous branches.

Most fibers of the anterior ramus of the first thoracic spinal nerve join the brachial plexus for distribution to the upper limb. The small first intercostal nerve is the lateral branch and supplies only the muscles of the intercostal space, not the overlying skin. In contrast, the lower five intercostal nerves abandon the intercostal space at the costal margin to supply the muscles and skin of the abdominal wall.

Anterior Abdominal Wall

The lower six thoracic nerves and the first lumbar nerve innervate the skin, muscles, and parietal peritoneum of the anterior abdominal wall. At the costal margin, the seventh to eleventh thoracic nerves (T7-T11) leave their intercostal spaces and enter the abdominal wall in a fascial plane between the transversus abdominis and internal oblique muscles. The seventh and eighth intercostal nerves slope upward following the contour of the costal margin, ninth runs horizontally, and the tenth and eleventh have a downward trajectory. Anteriorly, the nerves pierce the rectus abdominis muscle and the anterior layer of the rectus sheath to emerge as anterior cutaneous branches that supply the overlying skin (Figure 1-9).

The subcostal nerve (T12) takes the line of the twelfth rib across the posterior abdominal wall. It continues around the flank and terminates similarly to the lower intercostal nerves. The seventh to twelfth thoracic nerves (T7-T12) give off lateral cutaneous nerves, which further divide into anterior and posterior branches. The anterior branches supply the skin as far forward as the lateral edge of the rectus abdominis. The posterior branches supply the skin overlying the latissimus dorsi. The lateral cutaneous branch of the subcostal nerve is distributed to the skin on the side of the buttock.

The iliohypogastric and ilioinguinal nerves, both branches of L1, supply the inferior part of the abdominal wall. The iliohypogastric nerve runs above the iliac crest and splits into two terminal branches. The lateral cutaneous branch supplies the side of the buttock; the anterior cutaneous branch supplies the suprapubic region.

The ilioinguinal nerve leaves the intermuscular plane by piercing the internal oblique muscle above the iliac crest. It continues between the two oblique muscles to enter the

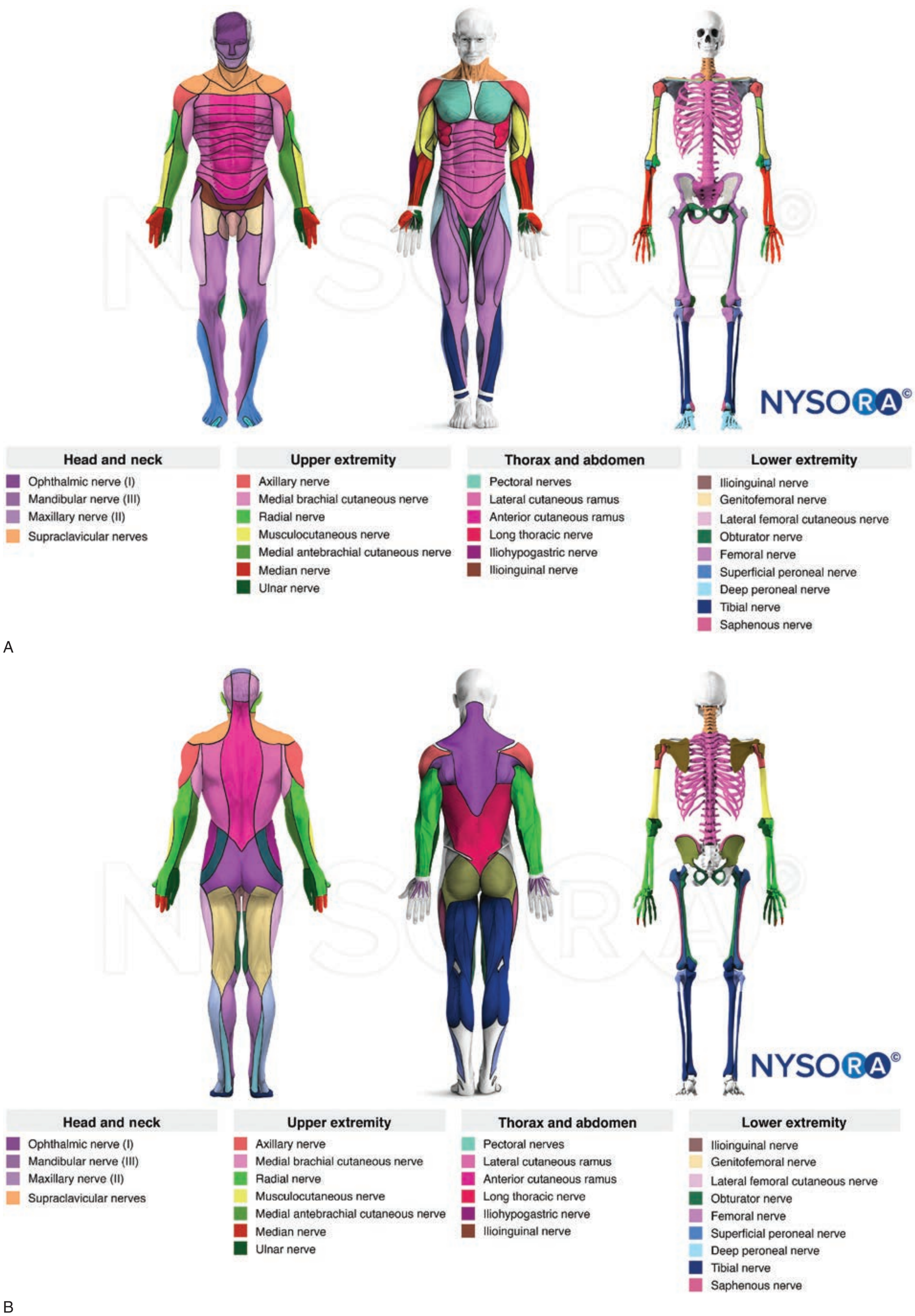

FIGURE 1-8. Distribution of dermatomes, myotomes, and osteotomes: (A) anterior view and (B) posterior view.